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Noble Gas Tracing of CO_2 Injection Fluids for Carbon Capture and Storage (CCS) using the miniRUEDI

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CO_2 mineral sequestration in basaltic aquifers is a promising method for long-term carbon storage, where injected CO_2 reacts with basalt to form stable carbonate minerals. While previous studies have demonstrated the feasibility of CO_2 mineralization, tracking injected CO_2-bearing fluids remains challenging. Traditional gas tracer approaches, such as $^{14}CO_2$, SF_6 and SF_5CF_3, pose environmental risks, logistical constraints, and high costs. To overcome these limitations, we deployed a "miniRUEDI" gas-equilibrium membrane-inlet mass spectrometer (GE-MIMS) for continuous and autonomous on-site dissolved gas analysis.

As part of the DemoUpStorage project, a CO_2 injection experiment was conducted near Helguvik, Iceland, where CO_2 was dissolved in seawater-derived groundwater before injection into a basaltic aquifer. Before dissolution, the CO_2 gas was labelled with He, which was tested as an inert tracer to track the dynamics of the CO_2 and the injected fluids in the aquifer. The miniRUEDI continuously monitored the partial pressures of CO_2, He, and other naturally occurring gases (N_2, O_2, Ar, Kr) in groundwater over an one-year period, providing real-time insights into CO_2 behavior underground.

Results confirm that He (or any other stable noble gas) effectively traces the movement of injection fluids within the aquifer. The He tracer appeared at a water extraction well about 100 m downstream of the fluid injection, indicating the arrival of the injection fluids. In contrast, the partial pressure of CO_2 did not increase at the extraction well, indicating that CO_2 experienced retardation or was removed from the water, which aligns with the anticipated mineralization of CO_2. Furthermore, the deployment of the GE-MIMS technique revealed no detectable increase or anomalies in CO_2 levels at a shallow observation well next to the injection borehole, indicating limited upward migration and reinforcing the effective retention of CO_2 in the aquifer.

This study highlights the potential of on-site mass spectrometry for real-time CO_2 and noble gas monitoring in carbon sequestration projects. The miniRUEDI provides a scalable and cost-effective alternative to conventional tracer studies, making it a key tool for future carbon storage efforts. The findings will support upcoming CO_2 sequestration projects and commercial deployments, enhancing CO_2 tracking and verification in geological storage.